USE OF TEMPERATURE ACCUMULATIONS AS AN INDEX TO THE TIME OF APPEARANCE OF CERTAIN INSECT PESTS DURING THE SEASON

BY

P. A. GLENN

State Department of Agriculture,
Division of Plant Industry,
Urbana, Illinois.

It has long been a matter of common observation that insects are very sensitive to temperature. As the cold of winter approaches many perish, and others go into hibernation to await the warmth of spring. In the spring they are aroused from hibernation and pursue their normal course of feeding, reproducing, and developing when the temperature rises to about 50° F., becoming more active as the season advances and the temperature rises until it reaches the optimum temperature for development in midsummer, when the rate of development is at its highest point. Above this point the torrid heat of summer is unfavorable for development of some species, resulting in the slowing up of their activities and development. As the temperature rises still higher, many go into estivation and others succumb to the intense heat.

In recent years many investigations have been conducted to determine more definitely the relation between temperature and rate of development in insects. The writer in 1915-16-17 collected data on the development of the stages of the codling moth, the life history, and the progress of the seasonal history, and sought to relate the temperature to rate of development and the accumulation of temperature units to progress of development, using out-of-doors temperatures in making the correlation.

The purpose of this paper is to explain briefly how temperature units may be used to forecast the date when any stage of an insect pest may be expected to appear, and to do so long enough in advance of its appearance to enable the grower of crops to take proper steps to ward off threatened injury.

In this latitude, temperatures range from about —30° to about 115° F. The range between these extremes may be divided into six zones, based on the reaction of insects to different degrees of temperature, as indicated below.

6. High Fatal Zone............	Fatality due to heat.
5. Estivating Zone............	Not fatal, but unfavorable for development.
4. Retarding Temperature Zone.	Rate of development decreasing with rise of temperature.
Temperature of maximum rate of development.	
3. Effective Temperature Zone.	Rate of development increasing with rise of temperature.
Zero of development.	
2. Hibernating Zone............	Not favorable for development due to lack of heat.
1. Low Fatal Zone............	Fatality due to lack of heat.

In these studies we are interested in the zones of effective temperature and retarding temperature, the relation of different temperatures to the development of the different stages and to seasonal development of insects.

Studies of the codling moth revealed that the rate of development in all its stages varied almost directly as the rise and fall of temperature within the zone of effective temperatures. Other investigators, by the use of apparatus for controlling temperature and humidity, have ascertained that changes in temperature near the zero of development have a slightly less value in producing change in rate of development and that similar changes in temperature near the upper part of the zone of effective temperatures have a slightly greater value, than do like changes in temperatures near the middle of the zone. They also have determined that humidity has a slight effect on the rate of development and on the zero of development, but these can not be detected by the use of varying out-of-door temperatures and it is unnecessary to take account of them for practical purposes. In these studies, therefore we are assuming that within the effective temperature zone the rate of development varies as the temperature.

It was also found that when the temperature rises above the point at which the maximum rate of development is reached, the rate of development was retarded approximately as it would be if the temperature had fallen a like amount below that point, and although this may not be quite accurate, it is assumed to be sufficiently accurate for our purpose. This relation enables us to convert retarding temperatures into equivalent effective temperatures, as the rate of development at two, three, or four degrees above the temperature of the maximum rate of development is approximately the same as at a temperature of two, three, or four degrees below that point. If, for instance, the temperature of the maximum rate of development of the pupa of the codling moth is 87° F., the rate of development of the pupa would be approximately the same at 90° F. as it would be at 84° F.

The limiting point between the hibernating zone and the effective temperature zone is called the zero of development. It is the temperature at which development ceases when the temperature falls and at which development begins when the temperature rises from hibernating temperatures.

The limiting temperature between the effective temperature zone and the retarding temperature zone is the temperature at which development proceeds at its highest rate.

These two points may differ for different insects and for different stages of the same insect.

The limits of the various zones have not been determined definitely for any insect, but the zero of development is in the neighborhood of 50° F. and the temperature of the maximum rate of development is probably between 85° and 90° F.

For the codling moth the zero of development for the larva and egg is near 50° F. and for the pupa 52° F.; the degree of the maximum rate of development for the egg, larva. and pupa respectively is near 88°, 85°, and 87° F.

The units of temperature accumulation used in this investigation are the day-degree and the effective day-degree. A day-degree is a unit of one degree operating for one day. An effective day-degree, or a day-degree of effective temperature, is a day-degree measured by temperatures within the effective temperature zone.

The day-degrees which accumulate above any temperature used as the zero for any day are the same as the average of the hourly temperatures above that zero.

To compute the effective day-degrees for any day during which the temperature does not at any time rise above the temperature of the maximum rate of development, add the hourly temperature readings for the day above the zero of development, and divide by 24, or add the hourly readings for each alternate hour and divide by 12.

To compute the effective day-degrees which accumulate during a day when the temperature for part of the time is above the temperature of the maximum rate of development, subtract from the average day-degrees above the zero of development, twice the average day-degrees above the degree of the maximum rate of development. The result will be the day-degrees of effective temperatures, or the number of effective day-degrees which accumulated during the day, and will serve as a quite accurate index to the value of the day in furthering the development of any stage of the insect or its life, or seasonal history.

The formula for the effective day-degree accumulations for any day may be written, $x = a - 2b$, in which "a" is the average of the hourly temperatures for the day above the zero of development, and "b" is the average of the hourly temperatures for the day above the degree of the maximum rate of development.

The following table illustrates the relation of temperature to the incubation period of the codling moth, the zero development being 50° F. and the degree of maximum rate of development 88° F.

TABLE I.

TEMPERATURE AND THE INCUBATION PERIOD OF THE CODLING MOTH

No. Obs.	Period in Days p	Mean Daily Tem. deg. F.	Average daily day-degrees			Total day-degrees	
			(50+) a	2(88+) 2b	(50+)-2(88+) a-2b	50+ ap	(50+)-2(88+) (a—2b)p
46	14.00	61.60	12.30		12.30	172	172
229	12.67	63.11	13.31		13.31	170	170
622	10.66	64.94	15.13		15.13	161	161
305	9.35	67.48	17.47		17.47	163	163
595	8.67	69.01	19.01		19.01	165	165
515	7.72	71.33	21.33		21.33	165	165
572	7.00	73.12	23.12	.01	23.11	162	162
335	6.60	74.86	24.86	.45	24.41	164	161
232	6.02	77.43	27.43	.96	26.47	165	159
249	5.95	78.71	28.71	.96	27.25	171	165
288	5.71	80.14	30.14	1.93	28.21	172	161
141	5.52	82.86	32.86	3.74	29.12	181	161
46	5.53	84.00	34.00	4.66	29.34	188	162
4175	7.67		21.70		21.33	166	163

Column 4 gives the average day degrees above 50° F. for the period (a); column 5 gives twice the average daily day-degrees above 88° F. (2b); and column 6 gives the remainders left after subtracting the retarding day-degrees in column 5 from the corresponding day-degrees in column 4, or the average daily effective day-degrees for the period (a—2b).

The periods (p) are given in column 2. Column 7 gives the products of corresponding numbers in columns 2 and 4, or the total day-degrees which accumulated above 50° F. during the period at the various temperatures (ap). Notice the wide variation in the numbers in